ILC, SuperKEKB and GammaFactory laser systems

Aurélien MARTENS (IJCLab Orsay)

Introduction

- Overview of what has been proposed for various other Compton (-like) projects
- My take away remarks for FCC-ee

ILC polarimeter(s) laser and challenges

Current design of laser rooms

Bartels et al., JINST 7 P01019 (2012), Boogert JINST 4 P10015 (2009), List @ALCW 2015

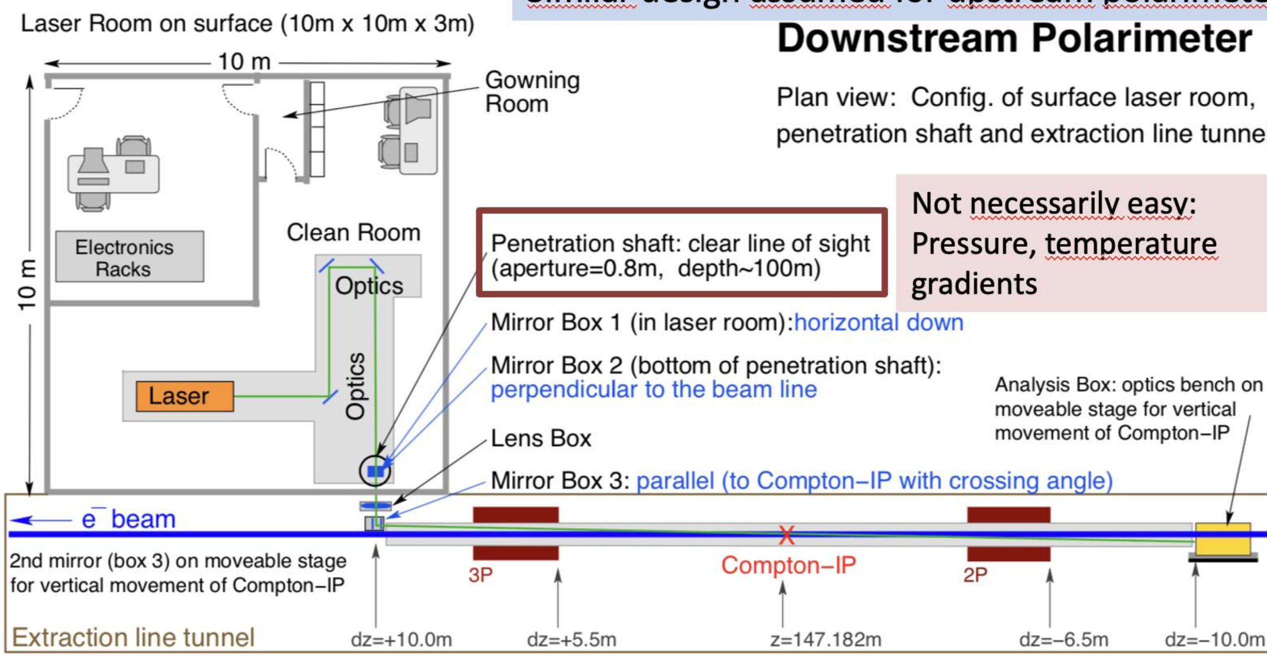
surface rooms: radiation hardness

Similar design assumed for upstream polarimeters

Downstream Polarimeter

Plan view: Config. of surface laser room, penetration shaft and extraction line tunnel

Not necessarily easy:
Pressure, temperature gradients



This design certainly require:

- Additional thick optical windows for the laser beam transport of the large beam (few cms)
- Careful compensation of pointing and position instabilities of the beam in the accelerator bay
- Relatively large optics (cost)

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ILC polarimeter(s) laser and challenges

Upstream Laser design: example of industrial laser

http://www.amplitude-systemes.com, Laser-Technik Journal (2/2016) 56

Laser specifications

Viable for 30µJ/pulse in red
Allow for continuous ellipsometry at 1.8 MHz ☺

	TANGOR	TANGOR HP
Average power	> 50 W	> 100 W
Pulse energy	> 300 µJ	> 500 µJ
Pulse duration	< 500 fs to 10 ps	
Repetition rate	Single shot to 40 MHz	
Wavelength	1030 nm	
Beam quality	Beam $M^2 < 1.3$	
Spatial mode	TEM_{00}	
Dimensions	68 cm x 48 cm x 16 cm	

100W in red → 50w in green

Specifications are subject to change without notice

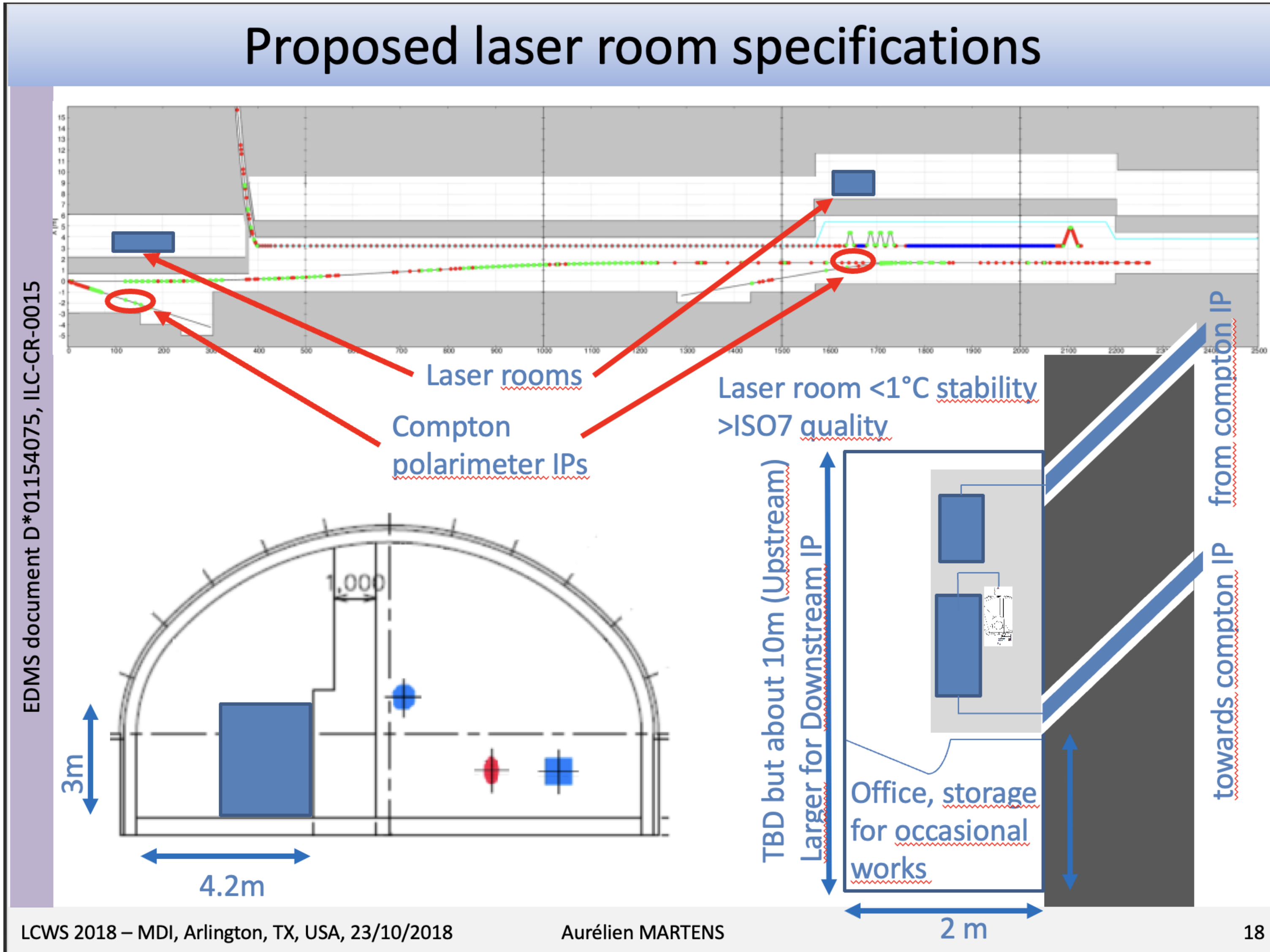
Ultra compact ! → integrate close to Compton IP ?

Applications

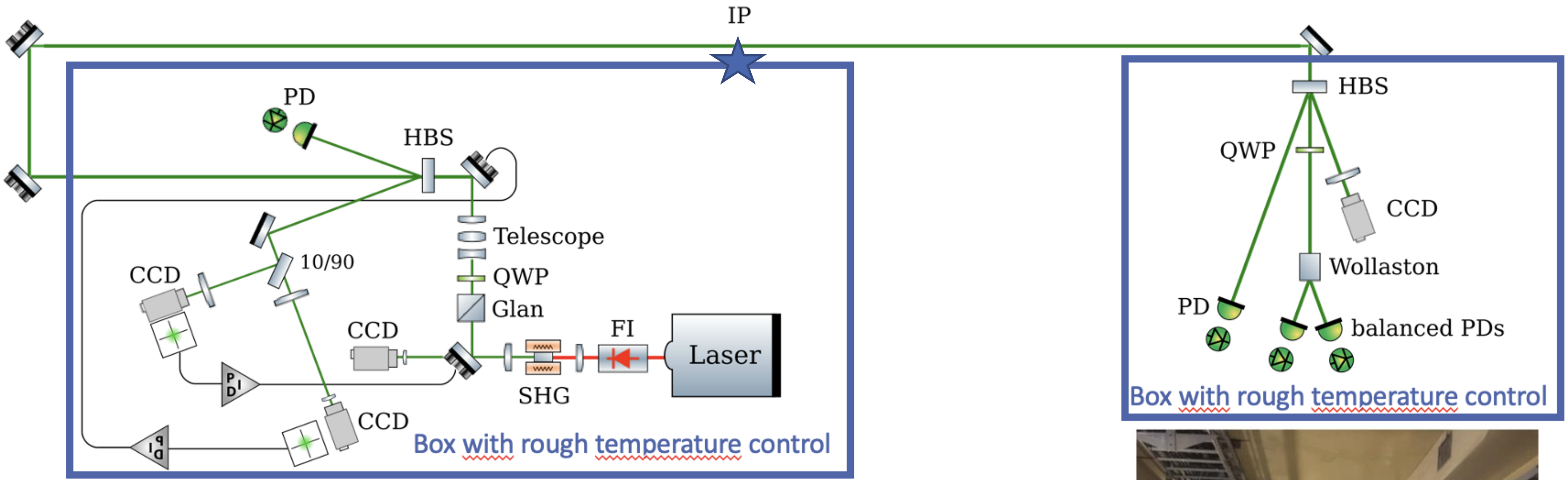
Demanding industrial sector: routinely operating systems

Concurrent designs certainly exist → detailed study of the market is required

ILC polarimeter(s) laser and challenges

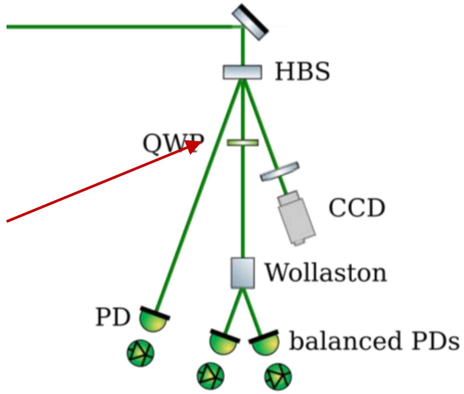


SuperKEKB laser



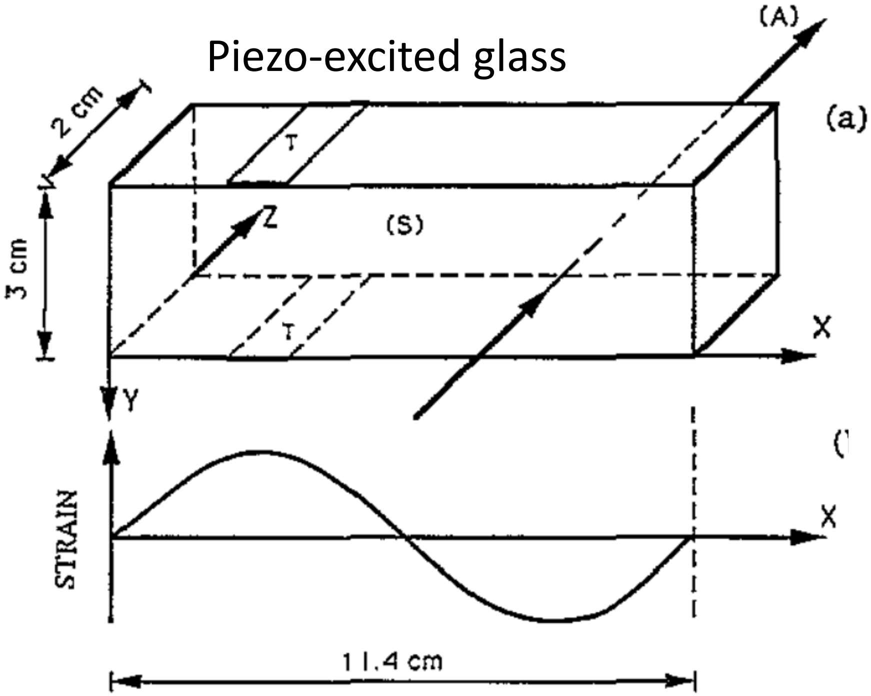
- Laser could be placed in accelerator bay below beam line
- Pulsed 250MHz green laser with a couple of Watts
- Automatic beam alignment and stabilization
- Currently working on real-time laser polarimetry based on photo-elastic modulation (on-going at IJCLab)

Current developments with PEM



Replace motorized QWP by PEM (photo-elastic modulator)

Piezo-excited glass



$$n_x \# n_0\left[1-\frac{n_0^2}{2}\left(p_{11}U_{xx}+p_{12}(U_{yy}+U_{zz})\right)\right]$$

$$n_y \# n_0\left[1-\frac{n_0^2}{2}\left(p_{12}(U_{xx}+U_{zz})+p_{11}U_{yy}\right)\right] \quad (2)$$

Modulated difference of refraction indices

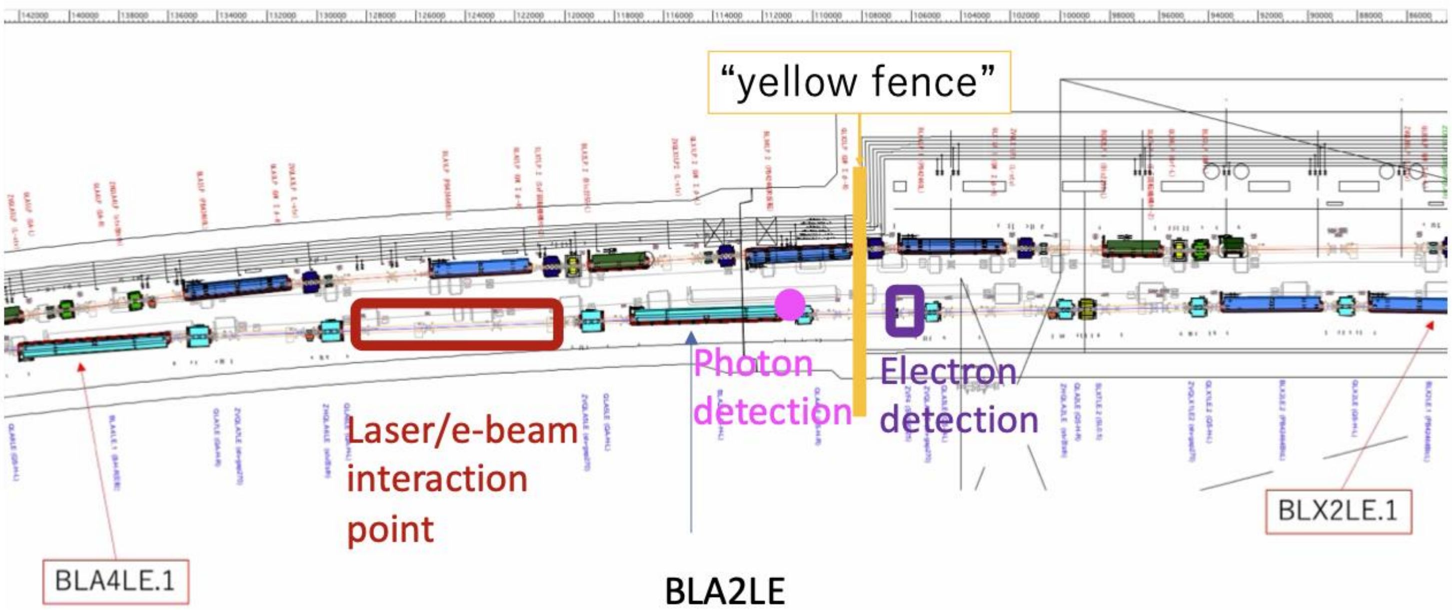
Modulation of phase of waveplate

SuperKEKB integration

BLA2LE/BLX2LE.2

Ideal in terms of spin projection on the longitudinal axis:

- 99%/85% of the value at IP if interaction before BLA2LE or BLX2LE.2
- Not so busy area

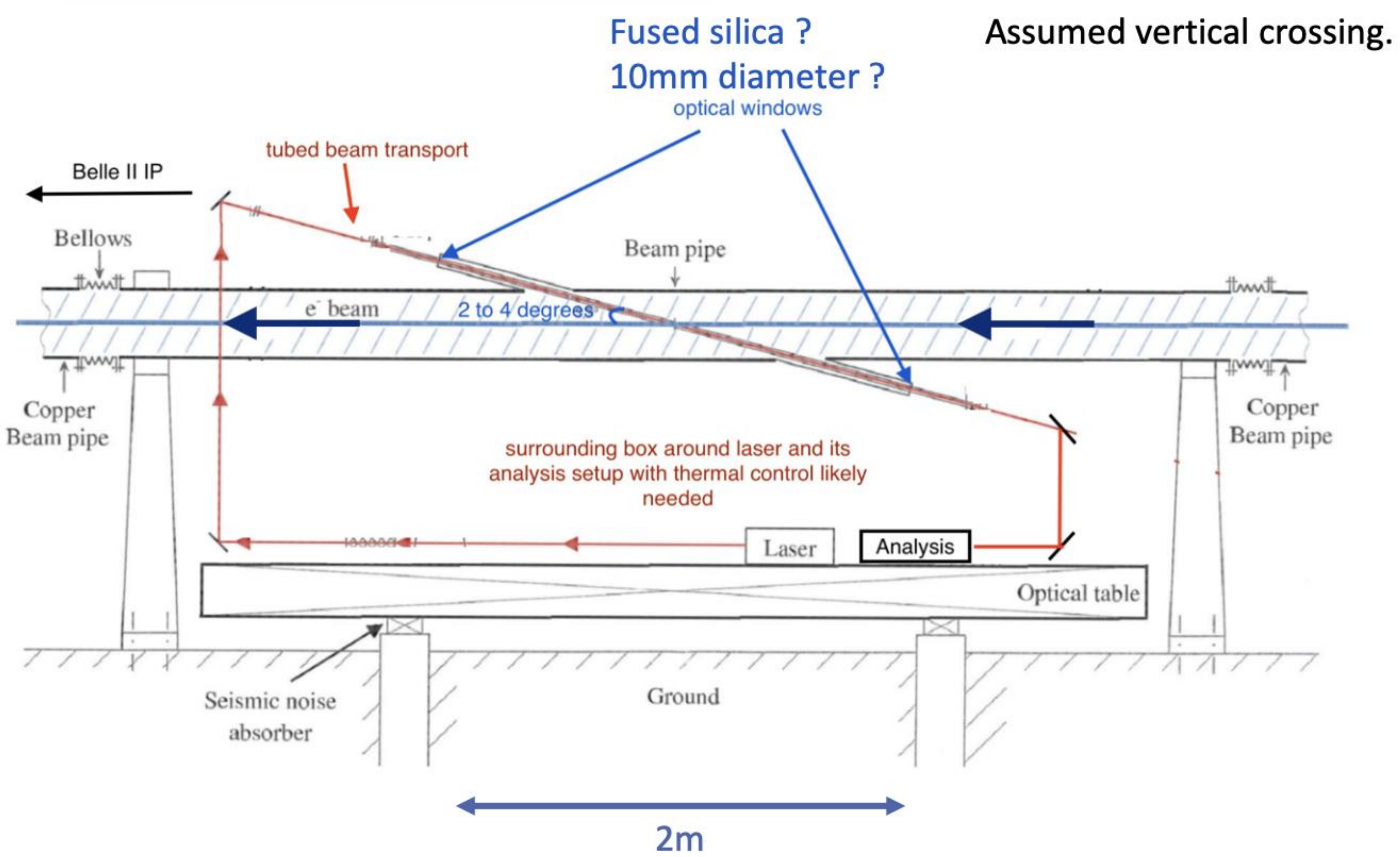


SuperKEKB laser chamber

Short beam transport, under air but tubed (at this stage)

Out of vacuum mirrors

Beam pipe for interaction chamber



Zhou, Ishibashi

SuperKEKB: impedance

Preliminary results of impedance calculation

- Impedance calculation by T. Ishibashi
  - Longitudinal wake with 6 mm Gaussian bunch is very weak.
  - The calculated loss factor, resistance and inductance are 4.4e-5 V/pC, 3.1e-3 Ohm, and 8.0e-4 nH, respectively.
  - Comparing with Table 1 of Ref. [1], these values are very small.

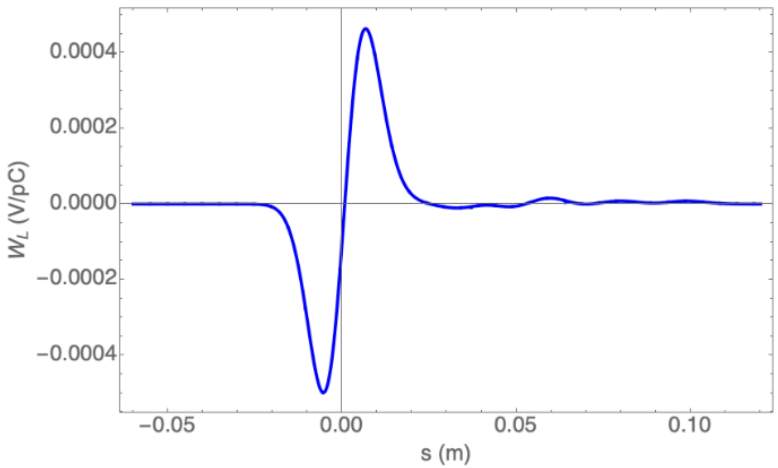


Table 1: Impedance budget for the SuperKEKB main rings. Summarised are the contributions to the loss factor $k_{||}$ [V/pC], the fitted resistance R [Ω] and inductance L [nH] for each type of components. The resistances and inductances are calculated at the nominal bunch lengths of σ_z=5 and 4.9 mm for LER and HER, respectively.

Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
Res. wall	3.9	231	5.7	5.9	340	8.2
Bellows	2.7	159	5.1	4.6	265	16.0
Flange	0.2	13.7	4.1	0.6	34.1	19.3
Pump. port	0.0	0.0	0.0	0.6	34.1	6.6
SR mask	0.0	0.0	0.0	0.4	21.4	0.7
IR duct	0.0	2.2	0.5	0.0	2.2	0.5
BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	3.8	0.5	-	-	-
Electrode	0.0	0.7	5.7	-	-	-
Total	19.2	1137	36.4	29.0	1677	62.1

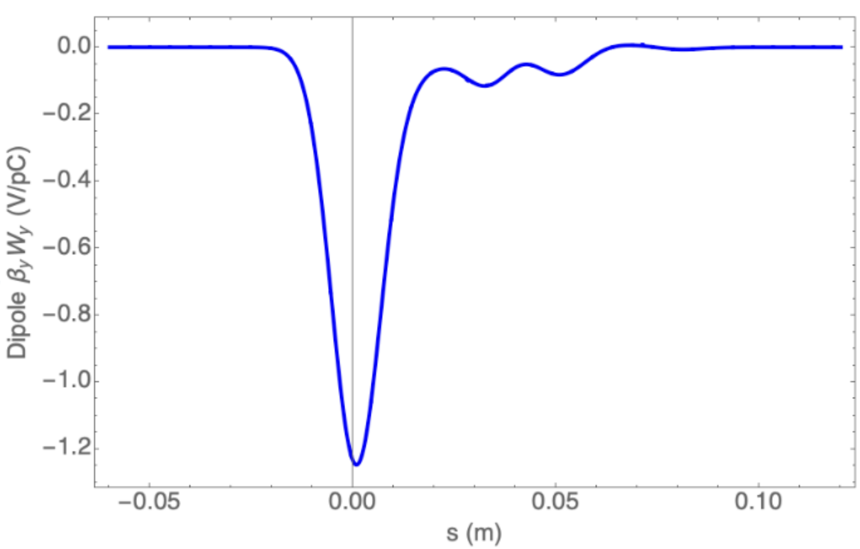
[1] D. Zhou et al., Impedance calculation and simulation of microwave instability for the main rings of SuperKEKB, in Proceedings of IPAC'14, Dresden, Germany.

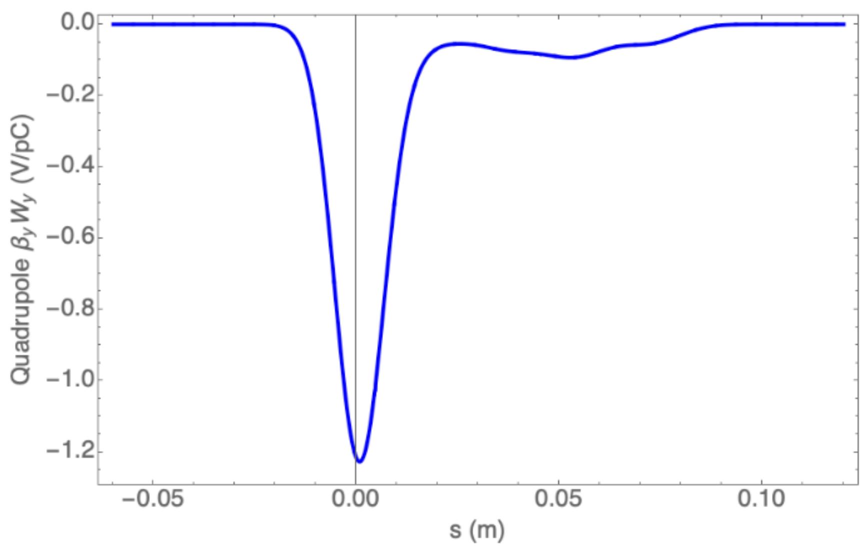
Zhou, Ishibashi

SuperKEKB: impedance

Preliminary results of impedance calculation

- Impedance calculation by T. Ishibashi
  - Vertical dipole and quadrupole wakes with 6 mm Gaussian bunch are weak.
  - The dipole and quadrupole kick factors weighted by beta function β_y=100 m are $\beta_y\kappa_y$=-0.89 V/pC and -0.88 V/pC, respectively. These values are very small, concerning the total $\beta_y\kappa_y$ of HER in the order of 10^4 V/pC.





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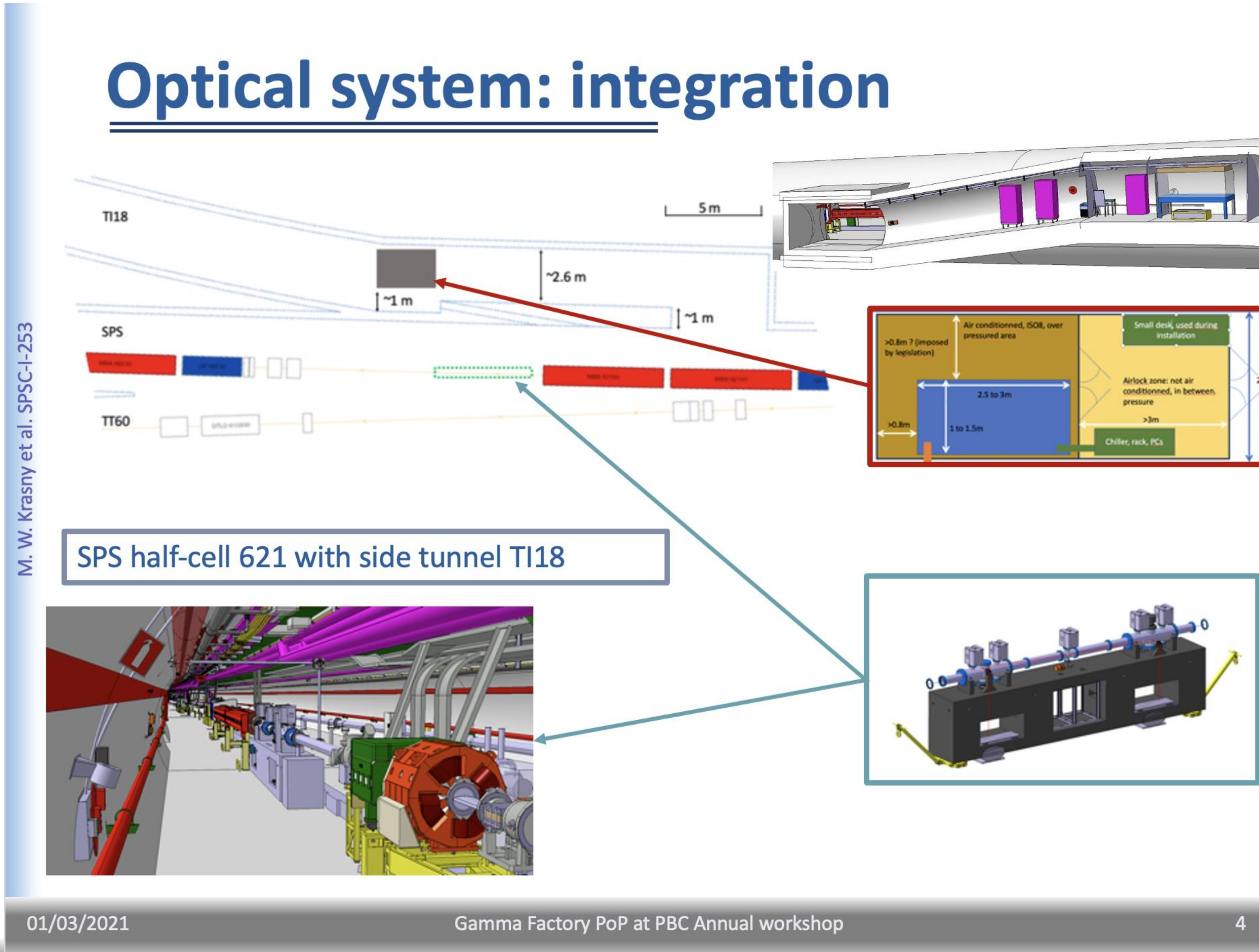
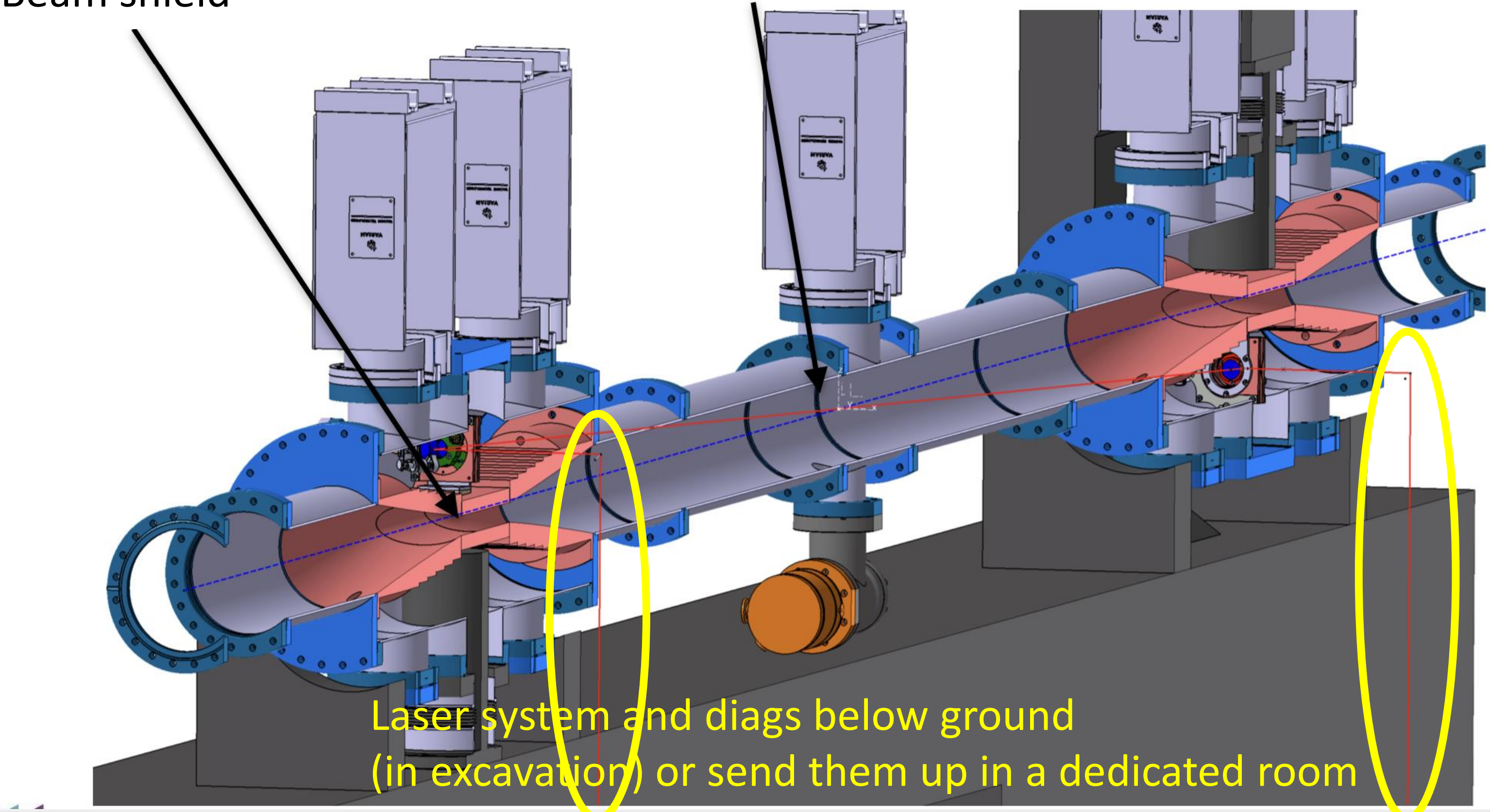
GammaFactory beam transport

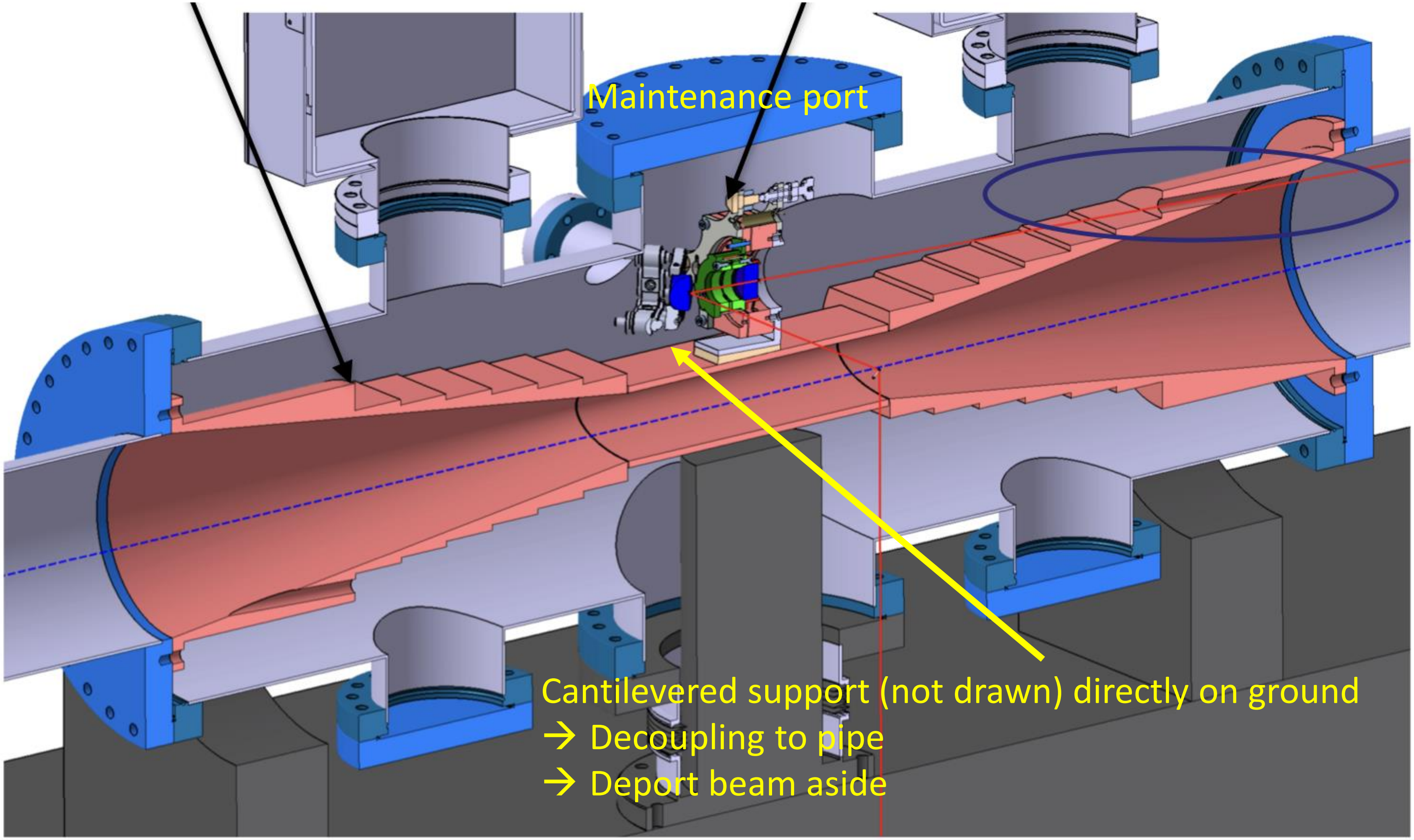


Gamma Factory Laser injection

Gamma Factory SPS proof of principle optical cavity mechanical design could be adapted ?



Gamma Factory Laser injection



Conclusion

Personal guess on what could be the laser and integration for FCCee polarimeters

1. A close-by laser room
   - Accessible during operation, even if remote operation is the goal it may be needed to have access from time to time – speaking about 24/7 laser operation
2. A short laser beam transport
   - Likely under vacuum (secondary probably for less vibrations, easier maintenance)
   - If possible on the floor (reduce vibrations).
   - Integrated motors, for auto-alignment/stabilization, few diag. cameras
3. A vertical crossing angle vacuum chamber similar to that of SuperKEKB (inspired from HERA cavity LPOL2),
   - no mirror in vacuum <u>of the accelerator</u>
   - radiation tolerance of windows need to be investigated
   - Injection mirrors supported directly on ground (decoupling to tubes) but placed in optical turning boxes in the vacuum of the transport line
4. Use modern modelock Yb laser systems
   - technology is industrially mature,
   - sync to accelerator is also customary for these systems (industry can sell),
   - can be burst amplified (pulse-picking + single pulse amplification)
   - May seed several different amplifiers in // if needed

Scattered photon rate

Laser-beam single pulse energy

Compton cross-section

pilots

Electron bunch charge (25nC or 6nC)

Geometrical factor

Photon rate $n = \sigma_C \frac{\mathcal{E}}{E_\lambda} \frac{Q}{q} \frac{\mathcal{F}}{4\pi\sigma_y\sigma_x}$

- $\mathcal{F}^{-1} = \sqrt{1 + \left(\frac{\sigma_z}{\sigma_x}\tan\frac{\theta_0}{2}\right)^2}$
- $\theta_0 \sim 2mrad$

Transverse beam sizes:

- $\sigma_{x,y,z} = \sqrt{\sigma_{x,y,z,laser}^2 + \sigma_{x,y,z,e-}^2}$
- $\sigma_{x,laser} = \sigma_{y,laser}$=1mm

Laser photon energy
(2.4eV for 0.5μm wavelengths)

From K. Oide

@Z		pilot	colliding
Collision		N	Y
Bunches/beam		~ 100	10000
Particles/bunch	10^{10}	~ 1	24.3
Energy spread	10^{-4}	3.8	13.2
Bunch length	mm	4.38	15.4
ε_x	nm	1.4	1.4
$\varepsilon_y/\varepsilon_x$	%	$\lesssim 0.1$	0.2
σ_x@laser / polm	mm	0.523 / 1.039	0.525 / 1.039
σ_y@laser / polm	mm	($\lesssim$ 0.007) / 0.027	0.012 / 0.027

Some possible laser systems

Nikolai's baseline

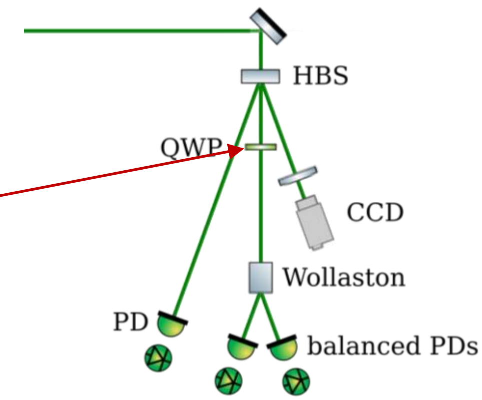
Laser param.	1 pilot	1 pilot v2	All colliding bunches (at Z)
Repetition rate	3 kHz	3 kHz	50 MHz
Pulse energy	1 mJ	1 mJ	100 nJ
Pulse duration	5 ns	5 ps (**)	5 ps (**)
Average power	3 W	3 W (***)	5 W (***)
Scattering rate	$1x10^5$/s (*)	$8x10^5$/s (****)	$1x10^6$/s (****)
Scattering rate per bunch	$1x10^5$/s (*)	$8x10^5$/s	$0.9x10^2$/s

Same oscillator may be used but two different amplification schemes

(*) Large piwinski contribution, nearly scales as crossing angle, very dependent on laser beam size (was $2x10^6$/s in ref. paper)
(**) Short pulse duration → broader laser spectrum, energy measurement from threshold more difficult
(***) Can be increased to typically ~100W (nowadays) but requires operational validation, management of thermal effects…
(****) not limited by Piwinski contribution → significantly increases when decreasing laser beam size

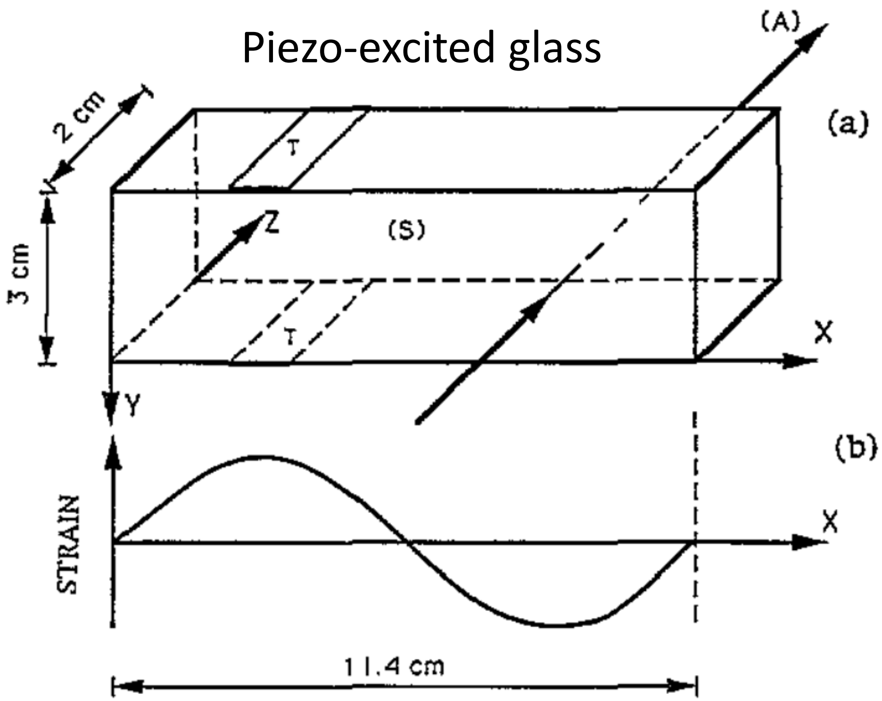
backup

Photo-elastic modulator



Replace motorized QWP by PEM

Piezo-excited glass



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Modulated difference of refraction indices

Modulation of phase of waveplate

D. Yang et al., J. Optics (Paris) **26** (1995) 151

PEM: principle for polarimetry

The detected intensity[7–9] takes the general form

$$I(t) = I\{I_0 + I_s \sin[\delta(t)] + I_c \cos[\delta(t)]\},$$ Intensity modulation on Photodetectors

$$\delta = \delta_0 + \mathscr{A} \sin \omega t.$$

Static birefringence

Harmonic contribution may also be required

To the first order in δ_0,

$$\sin[\delta(t)] = \delta_0 J_0(\mathscr{A}) + 2J_1(\mathscr{A})\sin(\omega t) + \delta_0 2J_2(\mathscr{A})\cos(2\omega t) + \cdots (\text{higher harmonics})$$

$$\cos[\delta(t)] = J_0(\mathscr{A}) - \delta_0 2J_1(\mathscr{A})\sin(\omega t) + 2J_2(\mathscr{A})\cos(2\omega t) + \ldots (\text{higher harmonics}).$$

Characteristic bessel expansion

More harmonics may be used

$$\begin{pmatrix} S_0 \\ S_\omega \\ S_{2\omega} \end{pmatrix} = I \begin{pmatrix} 1 & \delta_0 J_0(\mathscr{A}) & J_0(\mathscr{A}) \\ 0 & 2J_1(\mathscr{A}) & -\delta_0 2J_1(\mathscr{A}) \\ 0 & \delta_0 2J_2(\mathscr{A}) & 2J_2(\mathscr{A}) \end{pmatrix} \begin{pmatrix} I_0 \\ I_s \\ I_c \end{pmatrix}.$$

O. Acher et al., Rev. Sci.Instrum. **60** (1989) 65

PEM calibration setup

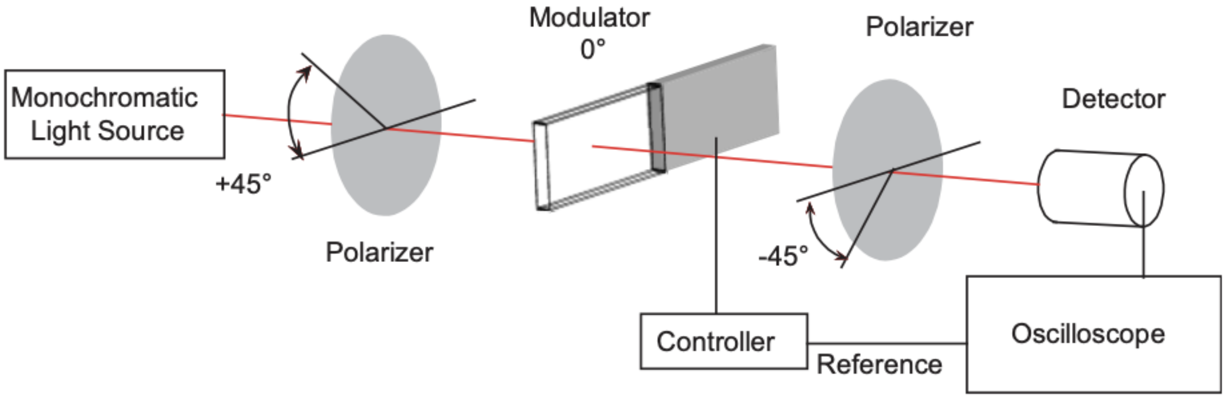
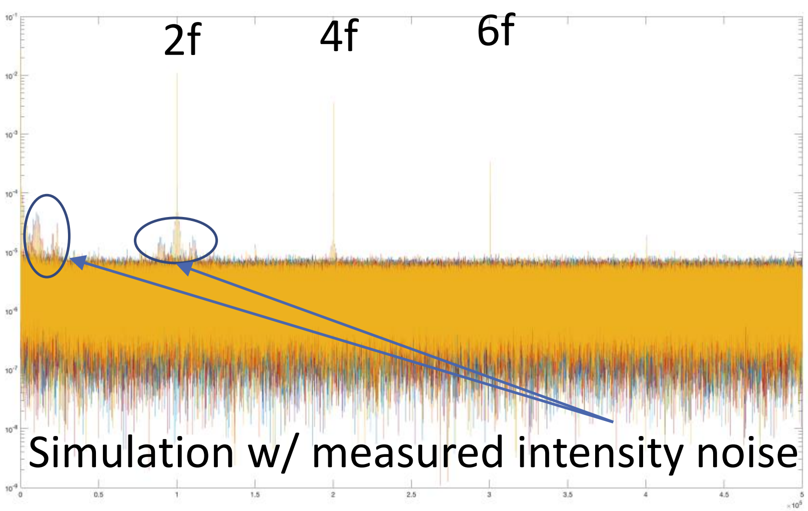


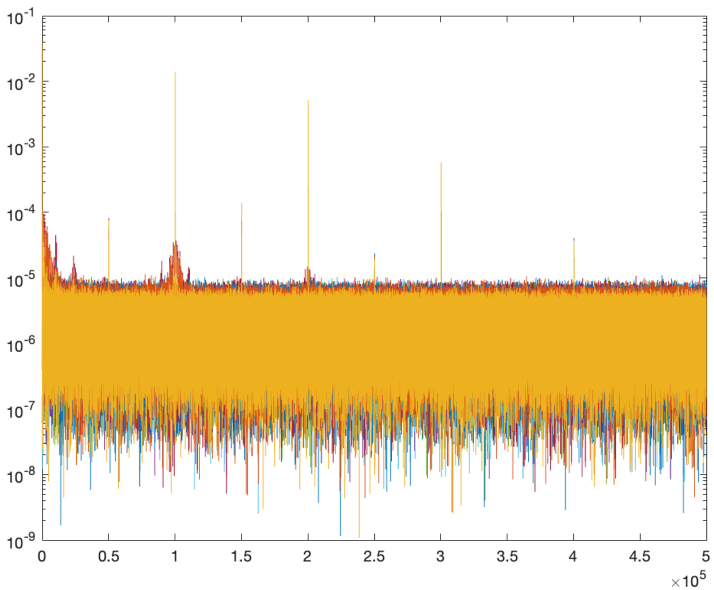
Figure A.1 Typical Optical Setup

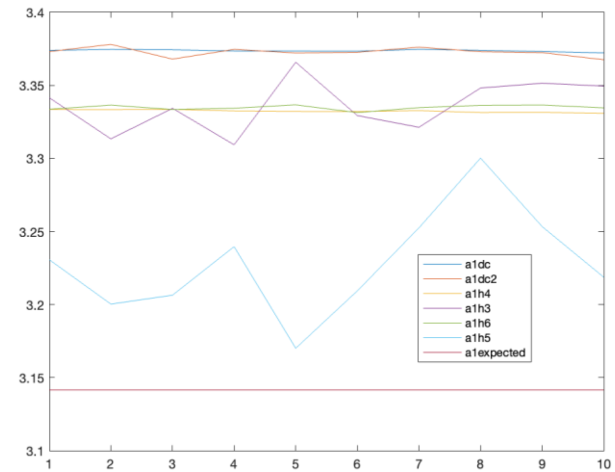
Acquire waveforms and then DFT

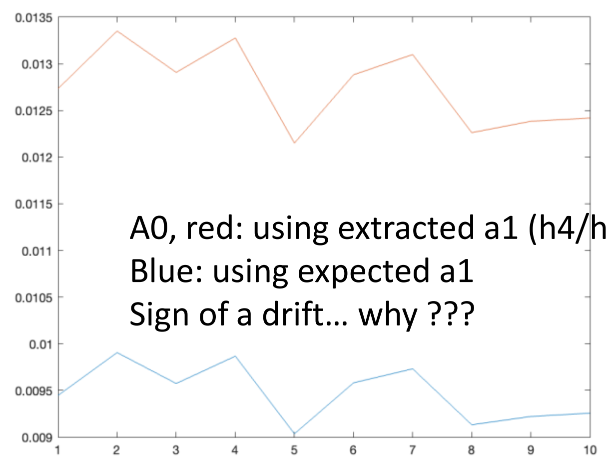


Data

A1 precision (repeatability) ~0.03%
Accuracy comparing h4/h2 and h2/dc ~ 1%
Accuracy of calibration (?) ~ 6%







A0, red: using extracted a1 (h4/h2)
Blue: using expected a1
Sign of a drift… why ???